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Safety assessment for temporary hospitals during the COVID-19 pandemic: A simulation approach

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ABSTRACT

Amid the devastating effects caused by the pandemic of the new Coronavirus (COVID-19), health leaders around the world are adding efforts to search efficient and effective responses in the fight against the disease. Conventional health centers, such as hospitals and emergency departments have been registering an increase in demand and atypical patterns due to the high transmissibility of the virus. In this context, the adoption of Temporary Hospitals (THs) is effective in trying to relieve conventional hospitals and direct efforts in the treatment of suspected and positive patients for COVID-19. However, some requirements should be considered regarding the processes performed by THs to maintain the health and safety of patients and staff. Based on the literature, we evaluated aspects related to patient safety in THs, especially linked to biosafety of medical facilities, and patient transport and visit. We highlight the analysis of flows and layouts, hospital cleaning and patient care. We described two case studies to demonstrate the proposed approach. As result, simulation tests improved safety metrics, such as waiting time for procedures, movement intensity in each area, length of stay and TH capacity. We conclude that the approach allows us to provide better THs that prevent cross-contamination, provide suitable care, and meet the demand.

1. Introduction

In March 2020, the World Health Organization (WHO) declared a pandemic for the new Coronavirus (COVID-19). COVID-19 appeared in Wuhan (China) in late 2019 and it has been spreading to several countries (Shu et al., 2020). Due to its high transmissibility, the disease has reached expressive numbers worldwide. In March 2021, more than 121 million people had already contracted the disease, reaching around 221 countries and territories (Ayouni et al., 2021). In the same period, the authors state that more than 2.5 million people died because of COVID-19. These numbers made the whole world mobilize to fight against the virus. Governments from the world's largest economies determined border shutdowns, travel restrictions, and quarantine, causing fears of an economic crisis and recession in an attempt to contain the spread (Nicola et al. 2020). The economic impacts caused by COVID-19 are in the order of trillions of dollars only in 2020 (Kabir et al., 2020). The authors point out that countries are experiencing a scenario of increasing investments in health, aiming for efficient responses to

combat and prevent the new Coronavirus.

According to Schuchat (2020), the acceleration phase of a pandemic was complex and required a fast adaptation of health systems for efficient responses. Despite the advance of vaccination against COVID-19 all over the world (Ogilvie et al., 2021; Freed, 2021; Cylus et al., 2021), there are countries where the pandemic has not been controlled yet, requiring extreme interventions in an attempt to control the disease (Ayouni et al., 2021). In this case, we stand out the adoption of Temporary Hospitals (THs). THs have improvised structures that require some adaptations. They are often set up in public places such as stadiums, exhibitions, and squares and there must be a proper preparation for isolation (Shu et al., 2020). Shu et al. (2020) emphasize that THs are essential in the treatment of patients infected with COVID-19, being an alternative to the lack of beds in conventional hospitals. Temporary facilities increase patient admission, contributing to efficient care for moderate level patients and inhibiting advancement to critical stages. THs may offer only the triage phase and initial assessment (Lee, 2020) or be an inpatient and intensive care center (Yuan et al., 2020). For Yuan

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et al. (2020), the main goal of THs is to treat patients with COVID-19 separately. Thereby, it is possible to isolate the infected people to prevent or reduce the spread of the virus to other patients, family members, and health staff. THs ensure that patients receive the necessary care in a timely and correct manner (Lee, 2020). In other words, if THs are correctly implemented, they increase people's safety, reduce infection risks and provide suitable patient care.

THs may be a good alternative to conventional hospitals, but there are some challenges to overcome. Building a TH requires the definition of several aspects, such as layout, setting, working mode of medical staff, patient management, admission and discharge standards, hospital operation (Yuan et al., 2020). Procedures and methods that follow distance and direct contact guidelines are necessary, ensuring safety for patients and professionals. Moreover, in extreme situations such as pandemics, speed and efficiency are key factors in the building of THs. Weissman et al. (2020) report that, in an attempt to combat COVID-19, hospital leaders face uncertainties in decision-making related to personnel planning, bed expansions, equipment acquisition, resource testing, strategies, and procedures. Therefore, many techniques and tools may assist in the planning and safety process of the THs, such as Simulation (Currie et al., 2020), Forecasting (Fanelli and Piazza, 2020), and Artificial Intelligence (Vaishya et al., 2020). In recent years, simulation stood out due to versatility and analysis capacity in decision-making for healthcare environments (Gunal and Pidd, 2010).

Simulation is an abstraction of a real process used from conception and planning to implementation and operation (Mourtzis, 2020). It became popular in the industrial field, as a powerful technique to provide decision support during different phases of a process or product. Simulation models allow evaluating behaviors, test scenarios, and carry out "what if" experiments without real interventions (Banks et al., 2010; Greasley and Owen, 2018). Gunal and Pidd (2010) report that simulation has been used since the 1980s for analysis and decision-making in processes involving health care. Salleh et al. (2017) highlight that the simulation can be used in four main approaches: (i) operations planning and health systems (resource planning aiming to optimize the provided services); (ii) decision making (evaluation of short-term and long-term effects on strategies); (iii) modeling of infectious diseases (prediction of diseases spread rate, evaluation of consequences and replanning) and (iv) miscellaneous studies (analysis of disasters or unusual situations).

The literature recommends four approaches to make improvements using healthcare simulation: System Dynamics (SD), Agent-Based Modeling (ABM), Discrete Event Simulation (DES), and Hybrid Simulation (HS) (Currie et al. 2020). Although the four approaches are efficient, Salleh et al. (2017) describe that DES is the most used and it represents actions at discrete time intervals. Moreover, DES allows decision-makers to plan, forecast, dimension, and improve processes and resources in tactical and operational management. Perumalla and Seal (2011) affirm that simulation models are preferable to model outbreak situations over epidemiological models based on differential equations. They affirm that traditional epidemiological models are based on simplified views, while simulation allows introducing many factors and parameters for the analysis and provides flexibility in the modeling. However, when using DES, the modeler should define the objective, rules, parameters, and assumptions with the stakeholders at the beginning of the project and the experts must be involved in all steps (Banks and Chwif, 2011).

Although, the strengths of DES in healthcare and to model outbreaks are scheduling and patient flow, sizing and planning of beds, rooms, and staff, and social distance (Gunal and Pidd, 2010; Currie et al. 2020), there are some limitations. Currie et al. 2020 say that quarantine, end of lockdown, and targeting vaccination are not solved by DES, but can be modeled using system dynamics and/or agent-based simulation. Then, the paper addresses DES for the safety assessment related to operations and processes of THs amid the COVID-19 pandemic. THs should consider good practices such as ensuring that patients are treated promptly, efficient resource allocation, and safe layout and people flow.

We propose safety dimensions related to hospital care processes using quantitative and qualitative evaluations provided by the simulation model. Moreover, we present two case studies of TH planning located in two cities in Brazil, highlighting the simulation contributions to assess safety in each one. In this paper, we refer DES as "simulation". Although not applicable at all stages of the actual pandemic, Chen et al. (2020) highlight that THs have an important role in future health emergency scenarios. In this case, it is essential to consider the lessons learned with the COVID-19 (Jin et al., 2020).

The paper is divided into five sections. In Section 1, we introduced explanations about COVID-19, TH, and simulation. Section 2 discusses safety dimensions in THs. In Section 3, we highlight how simulation is a powerful tool to analyze patient safety. Case studies are provided in Section 4. Finally, in Section 5, we present our conclusions.

2. Safety dimensions in temporary hospitals

Adopting THs represents a safety strategy to isolate patients with suspected COVID-19 avoiding cross-contamination. According to Lee (2020), contamination occurs from direct or indirect contact with people diagnosed with the virus. Therefore, with the THs implementation, patients with other illnesses are treated in conventional hospitals without any greater risk of infection. However, in THs focused on COVID-19 cases, staff must take extra care when performing processes.

Haghani et al. (2020) point out several safety dimensions related to the COVID-19 pandemic, which address safety about patient transport and visit safety, biosafety of medical facilities, specific medical procedures, treatments, food, social and domestic spheres. Although they identify works that evaluate care strategies in the first two dimensions, such as video consultation (Greenhalgh et al., 2020) and safety measures in a laboratory (Kooraki et al., 2020), they do not identify studies that comprise the assessment of the two dimensions in THs. Moreover, they do not present papers that use simulation to evaluate safety dimensions.

We propose the use of simulation to evaluate process safety of THs dedicated to patients with suspected COVID-19 especially for biosafety of medical facilities, and patient transport and visit safety. The study highlights two objectives: (i) reduce COVID-19 transmission within hospital facilities and (ii) provide suitable care to patients and reduce the chances of disease complications. The dimensions concern flows and layout, hospital cleaning, and patient care.

Despite its benefits, simulation may not be useful to evaluate all safety dimensions and determinants. We did not consider the impact of staff training, coordination, and communication. Initial communication and cooperation are important for the success of THs (Yuan et al., 2020), as well as staff education on COVID-19 and hospital systems and procedures (Chen et al., 2020; Fang et al., 2020). In addition, we do not consider the impact of materials and equipment quality and usability. For example, Hignett et al. (2021) highlight the challenge offered by ventilators rapidly produced by manufacturers with little know-how and not designed for users with less experience in this type of equipment. In this sense, other techniques may be used to assess such issues.

2.1. Flow and layout safety

Ensuring safety in flows and layout is one of the requirements for planning THs. Shu et al. (2020) state that hospitals should predict contaminations since the chances vary according to the characteristics of each area. They classify the areas into contaminated, semi-contaminated, and clean. Furthermore, hospitals focused on patient care with suspected COVID-19 must ensure suitable and safe spacing in corridors, between beds and chairs, in care rooms and in all areas where patients transit. However, THs generally face significant demands and need to increase their resource utilization. In this way, there is less chance of cross-contamination and, at the same time, efficient layout management. The patients and medical staff flows should be planned considering the safety of entering and leaving the hospitals. In extreme

cases of cross-contamination such as COVID-19, flows should be continuous, reducing the possibility of patients returning to areas where the procedures were performed. Moreover, in the planning phase, decision-makers should consider essential requirements such as emergency entrances and exits, access to ambulances, specific access for maintenance and replacement of inputs and resources, and different entrances and exits for patients and staff.

Ali and Alharbi (2020) report that a person infected with COVID-19 may contaminate others in a 6ft (1.8 m) radius of distance. Thereby, the planning phase must consider the places that have high agglomerations chances. Waiting rooms, queues, registration, and triage should be planned to maintain a safe distance between patients and staff to avoid cross-contamination. Ting et al. (2020) reinforce the importance of avoiding crowds in THs as much as possible while Haghani et al. (2020) affirm that decision-makers need to make researches about the control and management of crowdedness in these hospitals. THs should have separated waiting rooms where patients await medications, appointments, tests, and other procedures. All the management and planning of the THs' facilities, especially the waiting areas, need to be efficient and suitable to avoid or reduce crowdedness and physical contact to minimum levels. Therefore, the TH design must approach studies and analysis to obtain safe and suitable spacing (layout) and crowdedness control to guarantee the safe attendance of variable demands. Spacing and agglomeration measures prevent people who do not have the disease from becoming infected through cross-contamination.

2.2. Hospital cleaning safety

One of the main ways of COVID-19 infection is the handling of objects and contact with contaminated areas. The cleaning routines eliminate the virus on the surfaces, preventing the disease spread through indirect contact (Ali and Alharbi, 2020). Cleaning practices must be intensified since the virus that causes COVID-19 may survive from two hours to a few days on surfaces and floors (Ali and Alharbi, 2020). Ağalar and Engin (2020) emphasize that periodic cleaning routines should be planned to sanitize and disinfect beds, appointment rooms, reusable protective equipment, shared equipment, and circulation areas. Furthermore, cleaning routines should be performed after each appointment, procedure, or examination. Although cleanliness is extremely important for people's safety, it may affect the hospital's capacity. The cleaning procedure takes place over some time after using the rooms, making it impossible to attend new patients until the cleaning is finished. In this sense, the TH planning should consider safety regarding areas and equipment cleanliness and the impact on operations and processes.

2.3. Patient care safety

The main goal of THs is to assist patients with suspected COVID-19. He et al. (2020) states that professionals working against the virus should receive prior training to ensure safety for everyone involved in the care. Moreover, THs planning becomes more complex due to the following factors: (i) high patient diversity, which may range from suspicious to severe cases (Arya et al., 2020); (ii) limited number of physical and labor resources (Emanuel et al., 2020); (iii) improvised structures and environments that require more attention (Yuan et al., 2020); and (iv) atypical demand patterns (Emmanouil et al., 2020).

Decision-makers should follow strategies that have already been successful in other healthcare environments. Studies that maximize scarce resource utilization, provide equal treatment conditions, and prioritize the worst cases are benchmarks for planning a new TH (Emanuel et al. 2020). Care protocols adopted worldwide in the evaluation and triage are efficient to prioritize patients who arrive with symptoms of COVID-19 (Santana et al., 2020). Regarding resource limitations, Emanuel et al. (2020) and He et al. (2020) highlight that it is necessary to decrease the use of staff to reduce transmission risk.

However, there is a trade-off between better patient care and staff utilization. Therefore, health systems focus on determining optimal strategies and responses related to resource allocation and efficient planning for patient care (Moghadas et al. 2020).

Fig. 1 summarizes the safety dimensions of a TH. All actions aim to provide efficient care and reduce or eliminate cross and indirect contamination.

3. Simulation and safety assessment in temporary hospitals

Augusto et al. (2018) report many simulation studies for decision-making in health crises. Health leaders appeal to refined techniques to support the decision in cases of high demand, limited resources, and complex processes in atypical situations such as natural disasters, wars, and pandemics. Dieckmann et al. (2020) report that Simulation is crucial in health systems management and highlight that it helps in the analysis and improvement of flows, processes, and workstations. Finally, Currie et al. (2020) complement that simulation stands out for promoting analysis to reduce the strike on health systems due to the virus spread along with several countries. In addition to the approaches found in the literature, we observed that simulation is a useful and powerful tool for the evaluation of health process safety requirements.

The literature presents several methods of performing simulation projects (Montevecchi et al., 2015). They provide structured steps to obtain confident simulation models timely. In general, most methods start from conceptual modeling (process mapping), followed by data collection. Then, we move on to computer modeling, where all logic is converted into computer language through software or algorithms. The computer models must be validated aiming at the correct correspondence with the real processes (Sargent, 2014). After validation, the simulation model moves to the analysis phase.

We point out some limitations regarding the simulation model. Because the coronavirus pandemic is an atypical and unprecedented situation, the input data for the TH model may depend on information from other hospitals, health centers, and official articles or reports related to the disease. For the model building, we used data related to the demand, process time, and patient profile. The data came from the emergency departments where the hospitals were planned. For the COVID-19 infection rate, we used data based on articles from literature and the WHO (WHO, 2020). Fig. 2 shows the inputs we used to develop the simulation model.

Simulation may be used to evaluate THs safety at three decision levels: strategic, tactical, and operational, as proposed by Ahmadi-Javid et al. (2017). Strategic decisions are considered in the long-term and are not very flexible, such as changing locations and flows and adding new processes to the hospital. In a TH to combat COVID-19, the facilities operate only during the pandemic period. Therefore, strategic decisions are made in the hospital's operating time. Tactical decisions are medium-term and have a period ranging from one week to one month. New service protocols and changes in the sequencing activities should be taken at the tactical level. Finally, operational decisions are short-term and must be made within a day to a week. They concern the planning and improvement of hospital strategies based on their operational results, such as changes in work schedule and resource allocation. Simulation models are useful for measuring safety dimensions at the three decision levels.

3.1. Flow and layout safety assessment

Simulation allows carrying out tests to find the best layout, room's position, patient flow, and entrance and exit access. The model graphic aspect is important to evaluate the flow and layout safety dimension through simulation. However, the visual quality depends on the software used by the team. Mourtzis (2020) states that graphic resources are increasingly explored by simulation platforms and provide 3D visualization, virtual reality immersion and the models are closer to the real.

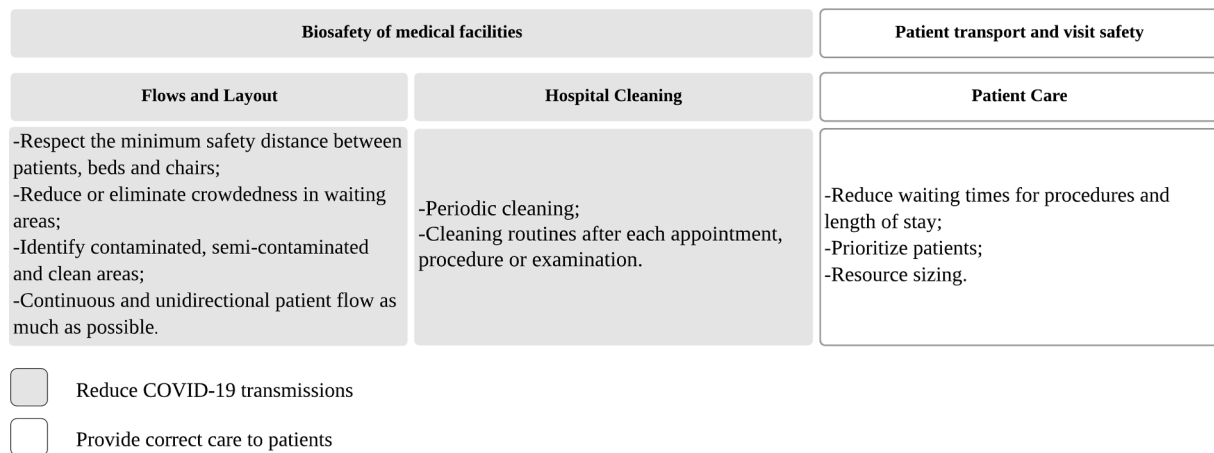


Fig. 1. Safety dimensions of TH.

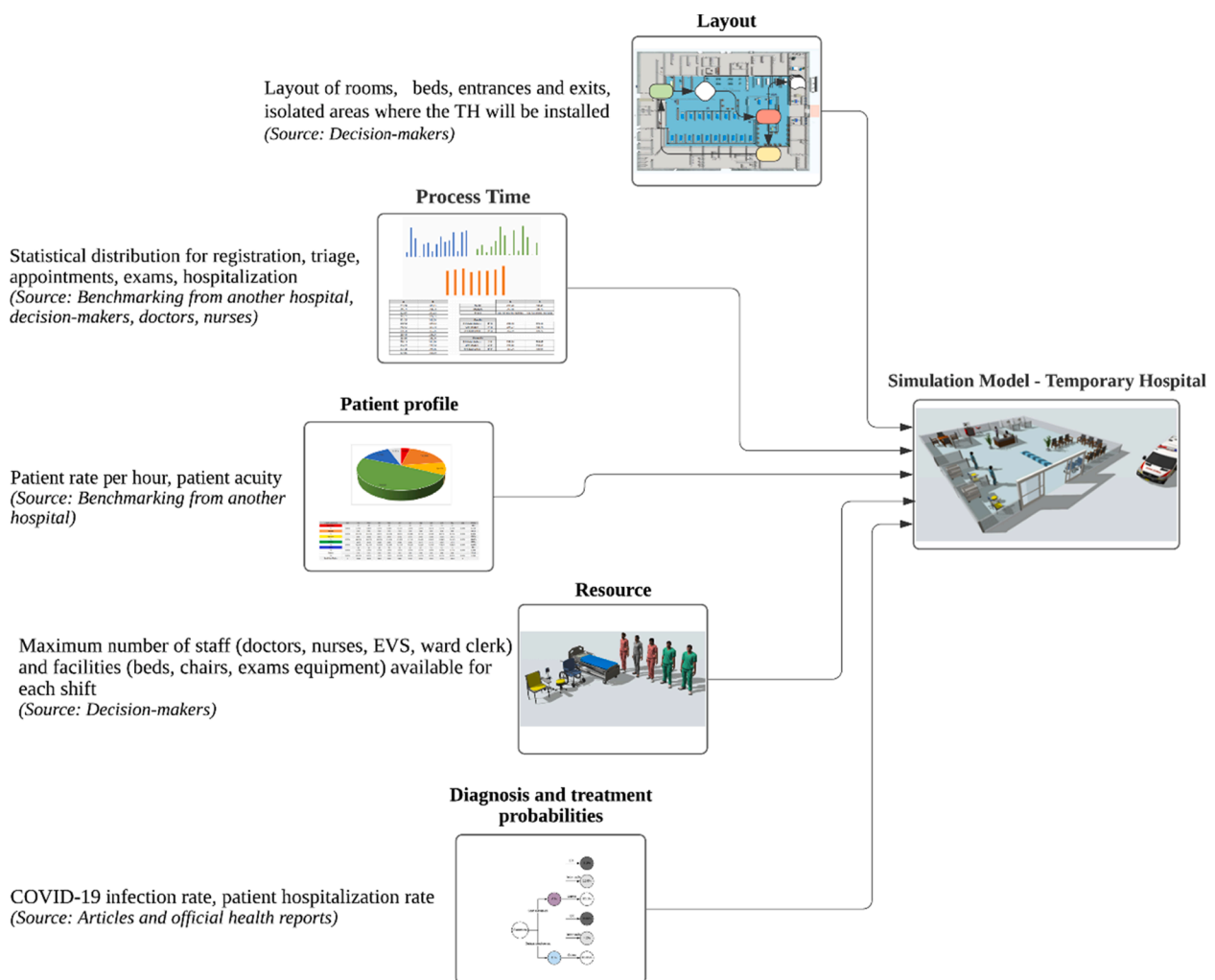


Fig. 2. Inputs in modeling and simulation.

These characteristics favor the simulation to analyze qualitative performances.

Robinson et al. (2012) confirm that simulation is a powerful tool for understanding the processes dynamics and flows in the health sector. The entire process of building the simulation model contributes to better decisions. Therefore, processes mapping and data modeling favor

assertive decisions regarding flows and layout. Moreover, some simulation software allows you to create heat maps that indicate points where there is more people's movement in the hospital. Heat maps help to identify locations susceptible to higher cross-contamination risks and provide effective directions to the assessment of other safety dimensions, such as cleaning.

Moreover, simulation enables to identify and manage crowdedness through the number of patients waiting for processes (triage, appointment, exams, medications, and hospitalization). In addition, crowding in waiting areas also depends on the demand behavior. Some places, such as the waiting room for triage, may have crowdedness during the rush hours. As a result, simulation runs show the number of patients waiting for procedures and the demand influence on crowdedness. Furthermore, if necessary, they allow us to test the expansion or creation of new waiting areas. The safety assessment analysis in personal contact has mostly quantitative content. Thereby, it is measured about the number of patients waiting for care in an area with a minimum distance of 6 ft (1.8 m) between each person.

3.2. Hospital cleaning safety assessment

Conventional hospitals already have a well-defined cleaning strategy. In a TH exclusively for the care of patients with suspected COVID-19, cleaning and sanitation strategies must be reformulated and intensified because virus transmissibility is higher than in other diseases. Consequently, if not properly planned, cleaning strategies may significantly increase patients' waiting time for locations and equipment. In this way, simulation provides metrics that indicate waiting time for processes affected by cleaning routines.

THs may combine different cleaning strategies. Most of the time, environmental service (EVS) techs are required to clean common areas. However, there are situations where doctors, nurses, or ward clerks clean their environment and instruments. In this case, simulation evaluates cleaning strategies, such as team size, responsibilities, and frequencies.

3.3. Patient care safety assessment

Safety in patient care depends on service strategies, such as resource allocation and work schedule, and the demand profile that may vary according to the period of the day or week. To solve complex problems, simulation stands out for its agility in scenario analysis and the possibility of using it with optimization techniques and the design of experiments. It is possible to obtain the ideal allocation of physical resources (e.g., beds and medication chairs) and staff (e.g., number of doctors and nurses per area). Therefore, simulation helps in assertive decision making in the long and medium-term and it allows to test flexible working schedules in advance.

Simulation evaluates waiting times for analysis of patient safety. The performance measures analyzed by the models must follow care standards related to patient acuity. Maximum waiting times for standard procedures such as door-to-triage time (DTT) and door-to-doctor time (DDT) must be respected. Moreover, simulation provides the patient's waiting time for hospitalization and length of stay (LOS). The literature presents reference values for the patient's risk classification and maximum waiting times for procedures (Christ et al., 2010) used by hospitals in several countries. However, THs may adapt the reference values in atypical situations. Table 1 summarizes examples of metrics

Table 1
Metrics evaluated by simulation for the safety dimensions.

Safety Dimension	Metric
Flows and Layout	<ul style="list-style-type: none"> • Spacing between people and locations; • Movement intensity in each area; • Number of patients waiting for procedures.
Hospital Cleaning	<ul style="list-style-type: none"> • Patient waiting time considering EVS group size; • Time interval between cleanings.
Patient Care	<ul style="list-style-type: none"> • Length of stay; • Door-to-triage time; • Door-to-doctor time; • Waiting time for hospitalization; • TH capacity.

evaluated by simulation for the safety dimensions.

4. Case studies

This section presents the analysis carried out in two simulation projects developed by the authors for planning THs, aiming at the safe care of patients suspected of Covid-19. We will show how simulation is a powerful and efficient tool to plan actions against pandemics. We used the FlexSim® software to simulate the process.

COVID-19 Response Center 01 (CRC-01) is a field hospital built in a gymnasium in a city around 100 thousand inhabitants in the state of Minas Gerais, Brazil. However, the TH has the potential to serve small close cities, reaching around 200 thousand inhabitants. The TH aims to care for all cases, including severe and critical patients. Moreover, local health decision-makers want to offer short-term hospitalizations (up to 3 days). The second hospital, the COVID-19 Response Center 02 (CRC-02) is an area planned by a large hospital, located in São Paulo, Brazil. CRC-02 aims to care for mild to moderate respiratory cases suspected of COVID-19. The area is an extension of the existing emergency department and aims to serve up to 400 patients daily, focusing on the diagnosis and fast treatments. In both cases, the THs operate integrated with an already established hospital. For CRC-01, only patients who need hospitalizations longer than 3 days are transferred to the main hospital. For CRC-02, severe and critical patients are transferred to the hospital's emergency department. We present the analysis according to the safety dimensions previously established.

4.1. Flow and layout safety

Simulation projects support suitable definitions of layout and flow safety dimensions. It encouraging the discussion of alternative layouts that aim to reduce the chances of transmission between patients. For the CRC-01, the simulation model and the 3D images and animation allowed the team to visualize patient flows and the hospital entrances. We developed a layout and flow (represented by Fig. 3) to reduce crossings and frequent returns to common waiting rooms by the patients. Examples of adopted strategies are: (i) distribution of the patients and staff inflow and outflow among three entrances; (ii) line layout definition, avoiding returns when possible; (iii) creation of a small waiting room for reevaluation or procedures to avoid multiple movements for the initial waiting room.

Some simulation software provides heat maps that indicate through color scales areas with greater movement, which present a higher risk of contamination. Fig. 4a shows the analysis of the heat map for the CRC-02, where red areas represent areas with greater movement. We identified EVS techs movements as one of the reasons for these areas' situation. The EVS techs were gathered in just one hygiene station, far from most places that need periodic cleaning. As an improvement, the project proposes three hygiene stations distributed by the TH. Fig. 4b shows a decrease in the red areas after the EVS redistribution.

In addition, the simulation model helps to define layouts that respect a safe distance between people and to assess patient density in places such as waiting rooms. In CRC-02, we considered the available area in the waiting room and the safety distance of 6 ft (1.8 m) between patients (Ali and Alharbi, 2020). Therefore, the maximum number of people standing waiting is seven. The simulation model allows estimating the number of people standing in the waiting room for different daily demands. In this sense, we evaluated if the requirement would be met in defining the TH capacity. Fig. 5 illustrates that demands greater than 300 patients/day may leads to situations of unsafe proximity for patients in the waiting room. If the TH presents a demand higher than 300 patients/day, the team should evaluate to increase the number of available resources, avoiding overcrowding in the waiting rooms.

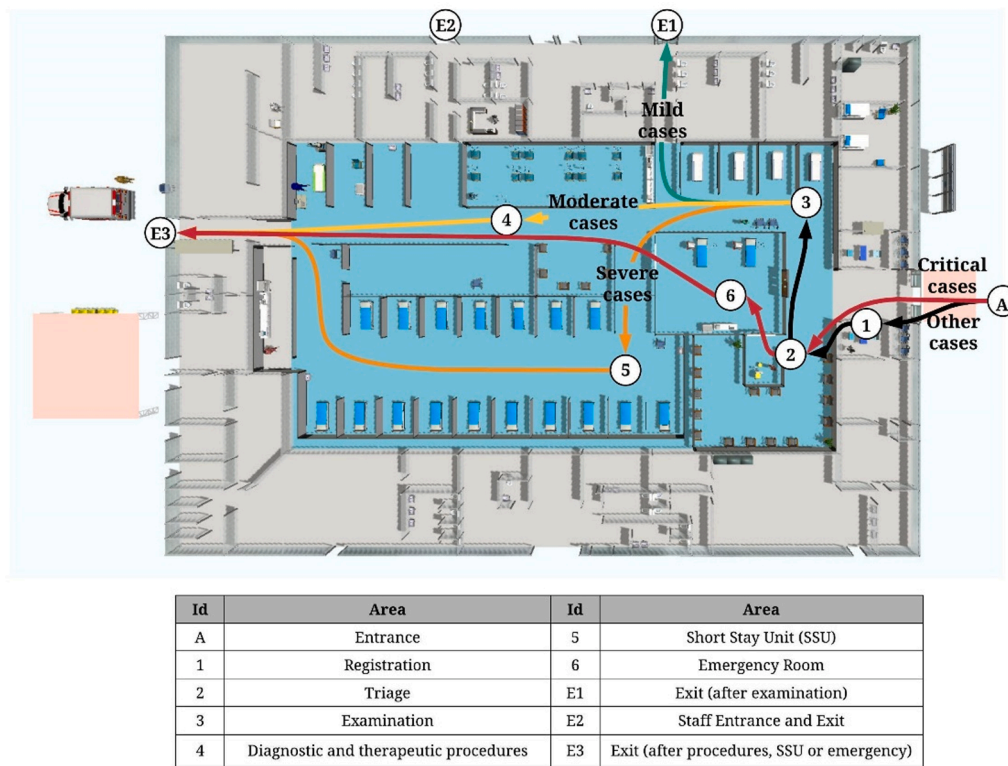


Fig. 3. Layout and Flow of the CRC-01.



Fig. 4a. Initial heat map.

4.2. Hospital cleaning safety

Simulation models support the definition of the hygiene strategy and the EVS team size. At CRC-01, the team discussed the cleaning strategy while building the simulation model. The hospital will have cleaning after patient leaves procedures and locations, and extensive periodic sanitation. Aspects of the strategy that were evaluated with the model include: (i) cleaning frequency; (ii) person responsible for cleaning; (iii)

and the time required for this process. Table 2 summarizes some of these definitions.

For CRC-02, we used the simulation model to assess the impact of different EVS team sizes on patients' waiting times, as patients are allocated to procedures and rooms only if these are properly clean. Fig. 6 shows that, for a demand of 300 patients/day, an EVS team size of 1 would cause a significant increase in patients' waiting time for medical examination and X-Ray. On the other hand, a team of size 3 would be

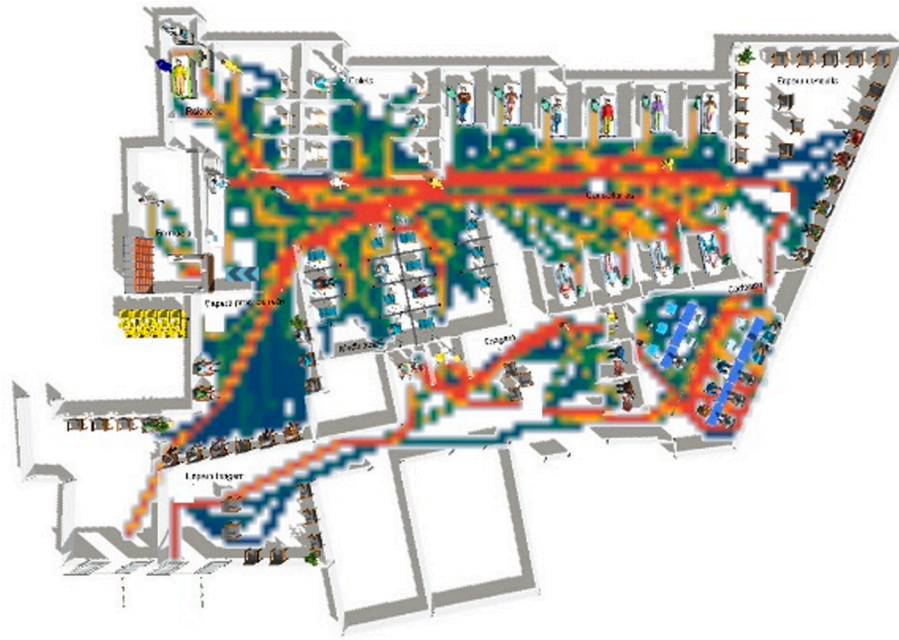


Fig. 4b. Heat map after improvements.

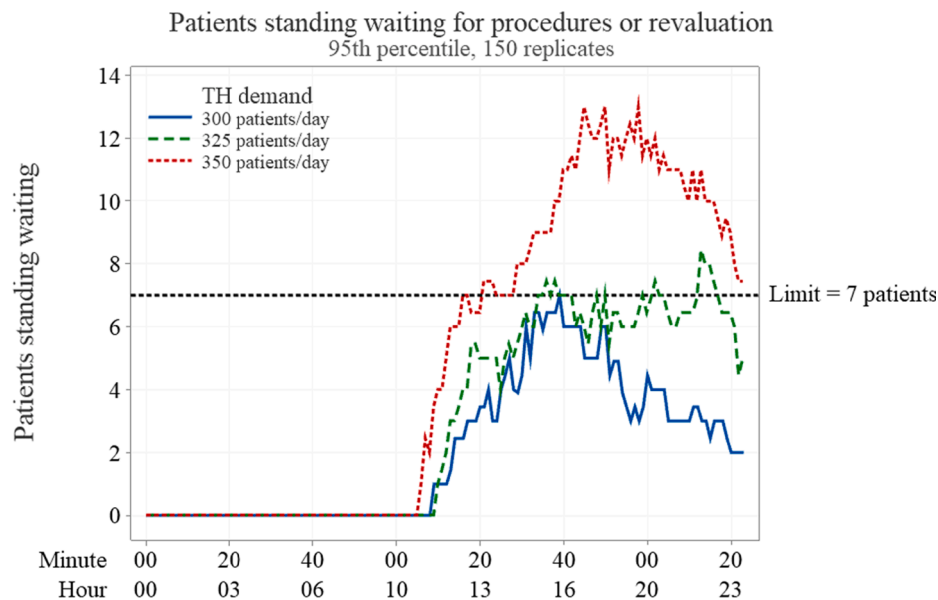


Fig. 5. TH Capacity according to personal contact safety.

Table 2
Cleaning strategies.

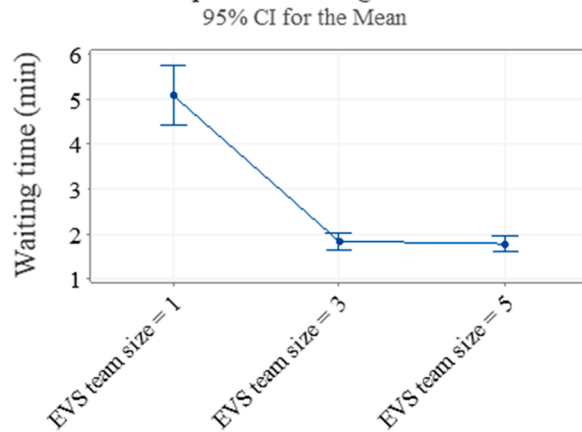
Location type	Location type		Periodic cleaning	
	Applicability	Responsible	Applicability	Responsible
Triage	✓	Triage nurse	✓	EVS team
Registration	✓	Ward clerk	✓	EVS team
Exam room	✓	EVS team	✓	EVS team
Medication	✓	EVS team	✓	EVS team
Collection	✓	EVS team	✓	EVS team
X-Ray	✓	EVS team	✓	EVS team
Emergency	✓	EVS team	✓	EVS team
SSU	✓	EVS team	✓	EVS team
Waiting room	X	N/A	✓	EVS team

enough.

4.3. Patient care safety

Defining the ideal number of resources in the system is one of the main analyses carried out by the simulation models. Resource sizing should be done to reduce patients' waiting times for triage, diagnostic and treatment procedures, improving their safety. Moreover, if patients do not need to wait too long, they are less exposed to cross-contamination. For the CRC-01, considering a demand of 200 patients/day, we evaluate different staff and location groups' size, especially during rush hours. Fig. 7a presents the impact of triage nurse group sizes on DTT. Fig. 7b shows how long patients wait for SSU admission, depending on the number of beds in this area. Both analyses aim to minimize patient waiting time. As a result, we identified in

EVS team size impact on waiting time for examination



EVS team size impact on waiting time for X-Ray

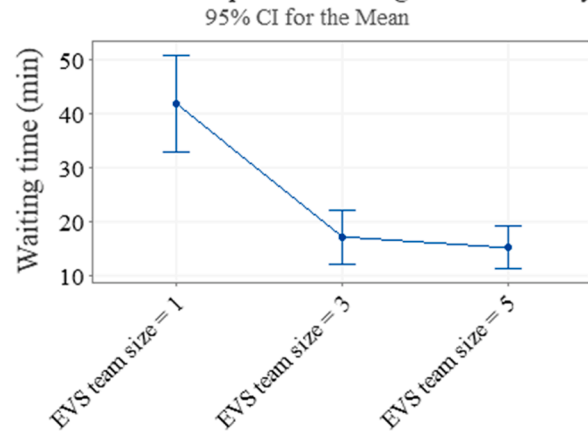


Fig. 6. EVS team size impact on waiting time for medical examination and X-Ray.

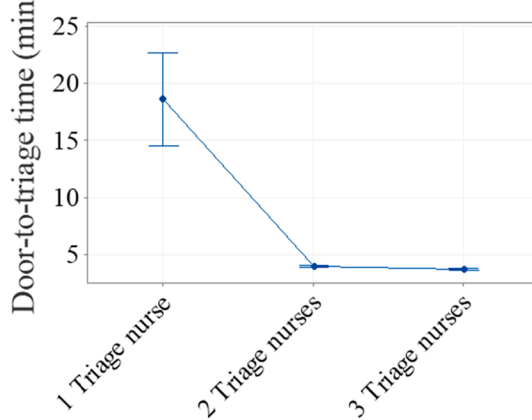
Door-to-triage time
95% CI for the Mean

Fig. 7a. Patient waiting time for DTT according to triage nurse team size.

Boxplot of door-to-doctor time

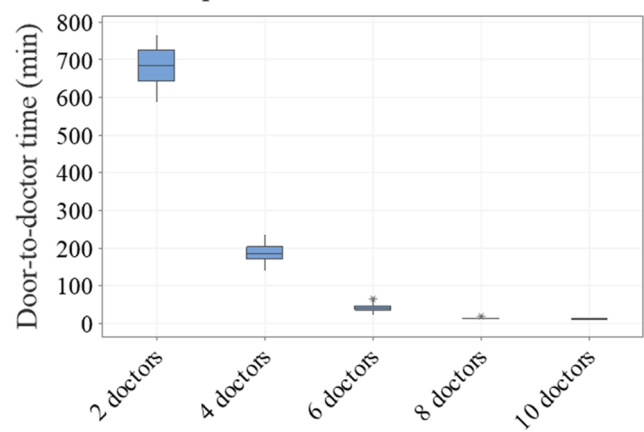


Fig. 8a. Patient waiting time for DDT according to doctor team size.

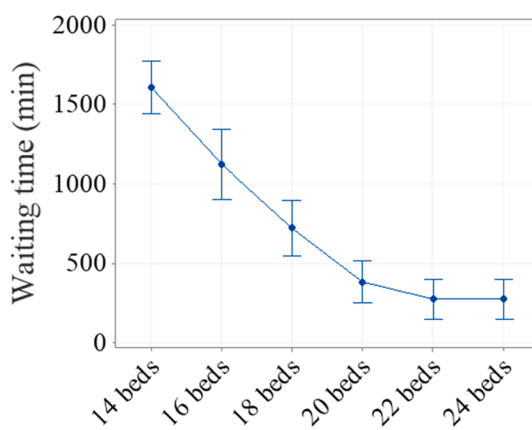
Waiting time for SSU admission
95% CI for the Mean

Fig. 7b. Patient waiting time for SSU admission according to number of beds.

advance the need for at least 2 triage nurses and 20 SSU beds to ensure patient safety.

Similarly, the CRC-02 project assessed the ideal number of doctors, especially during the rush hours, for a 300 patients/day demand. Fig. 8a presents the impact of this group size on DDT. However, sometimes it is

not possible to increase the number of resources to improve patient safety. In this case, the simulation model may help decision-makers assess the impact of different prescription protocols for diagnostic and treatment procedures. The goal is not simply to reduce prescriptions, but to guide its proper definition. In this analysis, decision-makers should assess the impacts on other quality care-metrics. In this sense, for the same project, we evaluated the impact of different prescription probabilities for Computed Tomography (CT) and Covid-19 test on LOS

Length of Stay Conformity vs Prescription Probabilities

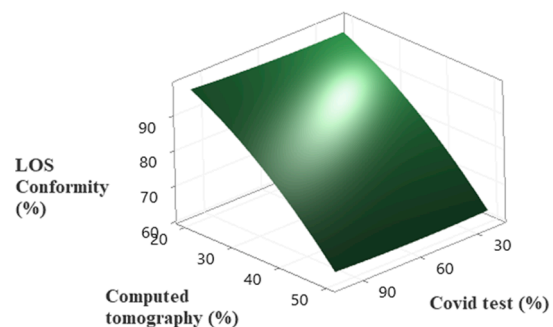


Fig. 8b. LOS Conformity × Prescription Probability.

conformity. It estimates the percentage of patients with LOS less than 146 min (goal defined by the team). Fig. 8b shows the analysis result. We identified that the expected demand for CT (20% to 30% of patients) would not decrease the LOS conformity below to 80%, which we considered a positive aspect. In addition, the percentage of patients who will test for COVID-19 does not represent a significant problem for LOS conformity.

5. Conclusions

THs are essential to relieve conventional health systems at critical moments and obtain better responses in case of health emergencies such as pandemics and natural disasters. Although not applicable for all pandemic stages, considering the COVID-19 pandemic, THs have been essential in several countries. In addition, they represent a great learning experience for health systems. Special hospitals, isolated and focused on COVID-19 care, represent a safety strategy since patients with other diseases become less exposed to the virus. However, there are some challenges to be overcome by decision-makers since THs should minimize the disease transmission, work with limited resources and deal with uncertainties. Based on the literature, we evaluated aspects related to patient safety in THs, especially linked to biosafety of medical facilities, and patient transport and visit. We highlight the analysis of flows and layouts, hospital cleaning and patient care.

Moreover, we proposed the use of simulation for decision-making and safety assessment. Simulation allows reliable analysis, experiments and predictions. COVID-19 THs should respect the minimum safety distance between patients and locations, reduce crowdedness, define cleaning routines, prioritize patients and reduce waiting times. Simulation helps us address these goals and it enables to plan safe and efficient THs. We described two case studies to demonstrate the proposed approach.

As result, simulation tests improved safety metrics, such as waiting time for procedures, movement intensity in each area, LOS and TH capacity. We conclude that the approach allows us to provide better THs that prevent cross-contamination, provide suitable care and meet the demand.

Our study presents some limitations. First, we only considered aspects related to patient safety. Second, we did not consider the impact of staff training, coordination, and communication since the focus of simulation is to plan and improve processes in tactical and operational management. Third, we did not measure the influence of materials and equipment quality and usability, as well as the use of personal protective equipment and hospital waste disposal. Finally, we did not evaluate aspects related to the coordination of the TH within a broader public action plan for the pandemic. As some of these issues are related to limitations of simulation itself, we highlight that, despite of its benefits, simulation studies do not guarantee suitable results in THs. Readers should consider integrating other techniques and areas for a comprehensive TH planning approach.

Further studies may address the use of simulation for the safety evaluation of healthcare workers. Moreover, we recommend a sensitivity analysis of TH performance to more pessimistic process times, which may reflect equipment with worse usability and unexpected operational difficulties. We also suggest the assessment of safety in conventional hospitals in responding to pandemics, considering surgery routines, maternity wards, and emergency departments.

CRediT authorship contribution statement

Afonso Teberga Campos: Conceptualization, Methodology, Software, Validation, Writing - Original Draft, Writing - Review & Editing. **Carlos Henrique dos Santos:** Conceptualization, Methodology, Writing - Original Draft, and Writing - Review & Editing. **Gustavo Teodoro Gabriel:** Conceptualization, Methodology, Software, Validation, Writing - Review & Editing. **José Arnaldo Barra Montevechi:**

Conceptualization, Methodology, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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